Hunan Daxue Xuebao/Journal of Hunan University Natural Sciences
ISSN：1674-2974 | CN 43-1061 / N

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

INNOVATIVE METHODOLOGIES FOR BIODIVERSITY IMPACT ASSESSMENTS

Dr. FAISAL A. OSRA

Associate Professor, Civil Engineering Department, College of Engineering and Architecture, Umm Al-Qura University, Makkah, Saudi Arabia. Email: faosra@uqu.edu.sa

Abstract

Biodiversity plays a critical role in sustaining ecosystems and human life, yet it faces increasing threats from development activities. This paper introduces innovative methodologies for Biodiversity Impact Assessment (BIA), enhancing traditional Environmental Impact Assessment (EIA) processes. It presents an in-depth review of emerging technologies—including remote sensing, predictive modeling, and automated monitoring systems—and their integration into biodiversity evaluation frameworks. Drawing on European initiatives such as the Lambinemes project, the study outlines practical tools and case studies that demonstrate improved planning, monitoring, and mitigation of biodiversity loss. The paper highlights the limitations of current practices, such as inconsistent data usage and insufficient post-project monitoring, and proposes a more systematic and data-driven approach. It also underscores the importance of stakeholder engagement, policy alignment, and spatial planning in achieving conservation goals. By bridging technological advancements with ecological data, the proposed methodologies aim to support more accurate, transparent, and impactful biodiversity assessments for sustainable development.

Keywords: *Impacts, Biodiversity, Biodiversity Offsetting, Neutralizing, Augmenting, Versus Significant.*

1. INTRODUCTION

The use of biodiversity in Environmental Impact Assessment (EIA) and the application of a methodology for Biodiversity Impact Assessment (BIA), which can be applied within EIA and in other circumstances affecting landscapes or Natura 2000 sites, is considered. EIA is a well-established process across Europe, with regulations in place in all EU member states as well as in many non-EU countries, although the specifics of EIA processes, good practice guidance and enforcement capabilities vary between countries. The process is designed to ensure that projects likely to have significant effects on the environment are subject to an assessment of their environmental effects before development consent is given. EIAs are mandatory for certain types of large infrastructure or development, and screening procedures should be used to determine whether EIAs are required for other projects that might have significant environmental impacts. The Ecospace study indicates that biodiversity loss and resource degradation could diminish human carrying capacity. [1], [2].

This paper describes a project known as Land Management and Biodiversity in European Mines, Elements of Success (Lambinemes), funded under the European Commission’s LIFE program. The aim of Lambinemes was to provide guidelines to avoid or reduce the impact of mining, quarries, and pits, on biodiversity by improving the collaboration of all stakeholders throughout the planning, operation, and after-use phases. The methodology for BIA developed within Lambinemes built on the objectives and requirements of the EU policy and legislation in relation to biodiversity [3]. There are acknowledged limits to the methodology for BIA set out within Lambinemes. It will not predict exactly what the impact of a development will be and there is always a risk that information used in the assessment will later be found to be inaccurate or incomplete. However, by considering the objectives and additional success criteria in combination with the proposed developments and mitigation measures, the methodology does provide a comprehensive and balanced approach to BIA.

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

2. UNDERSTANDING BIODIVERSITY IMPACT ASSESSMENTS

Introduction

Environmental Impact Assessment (EIA) is a key process in the EU that ensures environmental effects of significant projects are evaluated before development approval. EIA is required for certain large infrastructure developments, with screening procedures to assess other projects' potential impacts. This approach aligns with global policies, including those in the U.S. The EIA legal framework in the EU is guided by the EIA Directive (85/337/EEC), amended in 2014 by Directive 2014/52/EU, which mandates consideration of species and habitats.

Development consent is conditional on effective measures to avoid, mitigate, or offset significant biodiversity effects, particularly concerning protected species and habitats under the Birds and Habitats Directives. Required measures include avoiding negative impacts, promoting restoration, and ensuring like-for-like replacements, though practices may vary among member states. The mitigation hierarchy prioritizes avoiding significant effects and favors restoration over offsets, with long-term maintenance as a last resort. Specifically, the Habitats Directive's Annex IV allows for compensatory measures aimed at enhancing conservation knowledge and status. The Directive emphasizes no significant environmental deterioration post-measures, and in cases of scientific uncertainty, the environment must be prioritized. The EIA Directive 2014/52 obliges member states to prevent net biodiversity loss, especially of habitats or species listed in the Habitats Directive, impacting both Natura 2000 sites and beyond. [3] [4]

2.1. Definition and Importance

Environmental impact assessments (EIA) are performed globally, especially in Europe, where innovative methodologies are prominent. These assessments often stem from legal requirements, involving developers and regulatory bodies more than biological data owners. Effective practices include spatial data, GIS, biotope surveys, remote sensing, and predictive mapping. Developers utilize biodiversity data to identify potential impacts and minimize them, with public consultation during the EIA process. Nonetheless, the application of this data can be inconsistent and may not always benefit biodiversity. The text concludes with suggestions for effectively utilizing biodiversity data in EIA and other species inventory initiatives through various innovative data methodologies. [3] [5]

Environmental Impact Assessment (EIA) ensures that projects with potential significant environmental effects are evaluated before receiving development consent. It considers the environmental implications of policies and land use plans prior to proceeding. Impacts should be understood within the unique ecological context of the region, particularly those not preserved by protective measures. EIA helps identify combined impacts from various plans. Cumulative impacts arise from individual actions, where impact quality and context define overall effects. Impact estimations rely on multipliers, revealing full effects only after certain triggers. Management agreements are historical structures with limited relevance. A broad definition of impacts is essential to avoid "salami slicing." The mitigation hierarchy—avoiding, reducing, and compensating for damages—needs clear definition. [6]

2.2. Traditional Assessment Methods

Assessing biodiversity impacts is a crucial component of biosafety assessment. Despite its importance, biodiversity risk assessments are mandatory only for releases of genetically modified organisms in the European Union. Other technologies with potential adverse effects on biodiversity are also being developed and marketed, such as bio-pesticides, exotic pets or gene editing organisms. Nevertheless, biodiversity risk assessments are not necessarily mandatory for the release of these non GMMs.

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

Different methodologies exist to assess impacts of invasive alien species which can be transferred and adapted to these innovative organisms. [7]

Traditional biodiversity impact assessment protocols involve answering questions about the biology of introduced species, their distribution, and environmental effects. Recently, various methodologies for assessing impacts of Invasive Alien Species (IAS) on biodiversity have been developed and evaluated for consistency. A group of evaluators tested different protocols, documenting their assessments in detailed reports. Along with standardized protocols, experts received background information on impacts, relevant literature, and worksheets containing information on species introduction history and management costs.

They followed guidelines to assess IAS impacts on biodiversity, using a score scale for six potential effects, including impacts on populations, communities, ecosystems, and ecosystem services. The evaluation focused on consistency of assessment outcomes across IAS protocols and impact categories considered. [8]

2.3. Challenges in Current Practices

Current biodiversity impact assessment practices are inadequate for several reasons. Guidelines are typically vague, lacking specific standards for evaluating planning applications. Assessments are often rushed and may rely solely on desk-based analysis, neglecting necessary site visits or local ecological input. Consequently, crucial species assemblages and habitat conditions go unexamined, leaving the core question of "impact versus what" unanswered. Secondly, the approach to mitigation measures for adverse impacts is unclear. Although recommendations exist for protecting surface water from contamination, there's insufficient discussion on practical implementation. Additionally, there are no established standards for 'after care,' meaning annual monitoring of operational developments is neither common nor obligatory.

To address these issues, a structured assessment of desalination plants' impact on biodiversity is recommended. A comprehensive literature review on similar water-processing plants identified relevant local habitats and species that may be affected by proposed developments. This research recognized six habitats along with significant botanical, ornithological, and entomological metrics, which were evaluated during a site walkover focused on assessing species presence and habitat features. Conducted by experienced ecologists following a published methodology and structured questionnaire, the walkover also included general observations about site ecology.

Furthermore, there is a growing trend towards the use of automated ecosystem monitoring technologies. These methods can collect data at regular intervals over extended periods, mitigating issues related to temporal and spatial under sampling often seen with manual methods. This enhances statistical analysis and reduces observer biases. However, two main challenges have hindered wider adoption of these technologies: establishing a reliable long-term power source and ensuring effective data transmission. [3][9]

A variety of automatic systems exist for wildlife observation and monitoring vegetation, temperature, and chemical properties. While they can objectively track dataset changes, they fail to adequately assess other ecosystem aspects. Automated methods for monitoring species composition, invasive flora spread, and soil biota changes that indicate relationships with altered periphyton are not yet common. These signals require careful examination over different temporal and spatial scales. A diverse system spanning various ecosystem products at set intervals is necessary. Current commercial technologies for this task are cost-prohibitive. Our system, however, can accomplish this effectively and at a lower cost with a local mobile network link. [10]

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

3.1. Overview of Monitoring Technologies

Reliable information on biodiversity changes is crucial for decision-making, yet existing methods do not meet the need for precise, large-scale assessments. This review examines various monitoring technologies: ground cameras, UAVs, UUVs, acoustic recorders, and terrestrial robots. These technologies offer advantages over traditional methods, such as precise trait estimation, reduced disturbance, and the ability to cover larger areas quantitatively. As ecosystems face rapid changes, rigorously quantifying ecological processes becomes increasingly important. Automated systems avoid human fatigue and apply consistent methodologies, enabling the discovery of new ecological patterns through extensive data collection. For instance, a time-enabled robotic monitoring system recorded the first nocturnal moth pollination observations of Trifolium pratense, including insect thermal-camera detection across the Tyndall Glacier.

This showcases the necessity for robust detection technologies capable of analyzing large quantities of data for small or low-contrast organisms. Automation quantifies ecological interactions at scales difficult to achieve using manual methods, from population levels to individual behaviors. Most modern ecosystems depend on ecological interactions and feedback loops, yet traditional assessment techniques face challenges due to the often cryptic nature of these processes, which occur over extensive areas and timescales. The increasing anthropogenic alteration of ecosystems complicates predictions regarding resilience and functions, even though such predictions are vital to understand the impacts of human actions and preserve ecosystem services.

High-resolution data from various studies may enhance predictive frameworks and reveal complex network relationships. Certain mathematical properties in specific data structures could indicate early warning signs preceding significant transitions, like population collapses. Since organic transitions are rapid and irreversible, understanding the mechanisms behind regime shifts is essential for anticipating them and crafting mitigation strategies. High-resolution data from sensors and experiments can significantly support the emergence of early-warning systems in contemporary ecosystems. [11]

3.2. Remote Sensing Applications

Remote Sensing (RS) Applications are employed as Earth Observation for data collection implementation [12]. As regards development of equipment and techniques, capacity was multiplied about 5,000 times since 1960s. Due to the incredible advancements, satellite constellations are used, ensuring global coverage – wide band of resolutions, various devices and availability of imaging (from high monitor to full permanent online control). At present, a wealth of new geological data acquired by remote sense devices is used. There is a wide range of both free-of-charge and commercial resources. The efficiency and informational quality improve significantly, using modern geographic information systems (GIS).

This manuscript comprises six distinct sections, with the initial segment serving as an introduction. The subsequent sections delve into the realms of Remote Sensing Technologies, Applications in Environmental Monitoring, Challenges in Data Interpretation, Innovations in Methodologies, and Future Prospects. Each segment is crafted to deliver an in-depth exploration of the pertinent themes and their implications within the context of remote sensing. The introductory section will commence with a brief exposition on the pivotal role of remote sensing in contemporary research. Following this, a thorough examination of current remote sensing technologies will be undertaken, elucidating their capabilities and limitations.

Subsequently, the discourse will shift to the various applications of these technologies in environmental monitoring, emphasizing not only practical implementations but also theoretical frameworks. The discussion will further encompass the multifaceted challenges associated with data interpretation, highlighting issues of accuracy, accessibility, and integration. In conclusion, insights into innovative methodologies will be presented, offering a glimpse into the future trajectory of remote sensing practices, alongside recommendations for enhancing data utilization through advanced analytical techniques such as Artificial Intelligence and Big Data Analytics. [13][14]

3.3. Field-Based Monitoring Techniques

Birds are widely used as an indicator taxon for conducting ecological monitoring in tropical forests because they are easily identifiable and were one of the first taxa to be well studied. Over both ecological and commercial interests there is increased importance on the combined monitoring of floral and faunal biodiversity, leading to increased development and application of methodologies for joint surveying and assessment of these groups. One frequently used method for surveying bird populations is through the use of fixed width point counts. These involve a single observer recording all detected individuals at pre-determined time intervals [15].

The study also regularly assesses the vegetation structure at each point count location, usually over relatively broad scales to investigate the environmental mechanisms mediating the presence and abundance of different bird species. One direct measure of habitat structure that may be accurately and feasibly recorded is ground level information collected in situ at the point count location. Macro-habitat structures and resources have been shown to be important determinants of bird diversity and composition. However, the relationship between on-ground and large-scale habitat structure is complex and may vary across forest types.

Another commonly used method for assessing biodiversity is mist netting, especially for monitoring forest bird species. Mist nets capture birds regardless of species and can be set up from the ground. However, they may bias species composition due to their selectivity for certain bird behaviors, which can be influenced by net avoidance behavior over time, reducing capture efficiency. This study evaluates 2 years of bird data from a diverse, old-growth tropical forest in Malaysia, utilizing both mist netting and point count transects, with habitat variables measured at each location. [16]

3.4. Data Collection and Management

Under adverse habitat conditions, professional data acquisition can be confirmed by spatial image documentation from the field or lab. Data is tagged to verify observations and uphold spatial and temporal standards. Sample containers must feature QR-codes with a 128-bit UUID, positioned for automated processing. Additional details like project names or sampling data can accompany the QR-code. While sampling methods can be standardized, they must also adapt to local conditions and can sometimes fail to yield physical samples due to factors such as size or danger. Camera-equipped GNSS-enabled smartphones facilitate practical imaging of spatial data without disturbing sampling.

Using a smartphone app, image documentation allows for replicable spatial sampling and proof of sampled organisms. Previously, image and label management was labor-intensive; now, batch processing with QR-codes and GPS metadata enhances data collection. This method provides a reproducible way to digitally document biological and environmental samples. Standard smartphone apps and manual workflows often lack efficiency, but batch processing ensures accurate collection of all essential metadata. In biodiversity assessments, effective data collection is critical to understanding biodiversity influences, drawing from field surveys, remote sensing, and existing databases. [17][3]

Prioritising biodiversity conservation requires knowledge of species distribution to address threats, yet most species lack this data. Advancements in technology for biological and physical data collection are generating new data sets to fill these gaps. Improved modelling techniques offer further opportunities to integrate this information into complex models.

One approach is statistical modelling, which explores relationships between response and predictor variables, enabling predictions across various environmental conditions. Predictive models quantitatively describe environmental filters influencing biotic communities and their abundances. The ensemble species distribution model (eSDM) toolbox, which includes multi-species and variable-response approaches, is widely used.

Techniques like boosted regression trees (BRT) help predict diverse fish biodiversity metrics from remotely sensed and multibeam habitat classification data. We investigate which biodiversity metrics can be best predicted, how predictor variable performance impacts outcomes, and the advantages of different habitat classification data sources. Habitat data was gathered at Cocos Island and East Madang using multibeam sonar for bathymetry and backscatter, while water column backscatter informed the Predicted Fine-scale Benthic Complex (PFC) classification. To link the PFC classification to Cocos Island's marine habitat, predictor variables were also generated from high-resolution satellite data and hand-digested observer data. [18]

4.1. Introduction to Predictive Modeling

Predictive modeling—defining a correspondence between a set of response variables and a set of predictors and using this correspondence to predict unknown responses from the predictors—can be a useful tool to use for the assessment of biodiversity impact over time. Predictive modeling is a widespread approach in machine learning (ML) and, more broadly, in Artificial Intelligence, in numerous applications. In the biomonitoring domain, recent papers proposed to use it for the prediction of undetected species used as indicators of temporal deterioration.

Discussions about (1) the process to select the ideal modeling procedure for a given data set, (2) whether and how a given modeling approach performs better than another, and (3) the process to select the optimal search sampling strategy consistent with the modeling procedure, can help to raise awareness among end users about the process and difficulties of evaluating modeling procedure performance and selecting appropriate evaluation procedures [19].

The data set presented in this paper consists of raw counts of the occurrence of 97 aquatic macro-invertebrates/Plecoptera species taken at 397 sampling points from 2015, used as training data, and 398 sampling points from 2016, used as testing data. The MWN data set, composed of overdispersed, zero inflated species abundance data, has been used as the basis for the comparison of different ML methods by several research teams. Threes were fit with earth and random forests during the 4 sampling functions tested.

This introduction is followed by a brief description of the widely used methodologies for predictive modeling. This technical report is not intended to be exhaustive on each of these methods. It provides a broad view on a recent paper with the participation of researchers who describe the difficulty of comparing different ML methods for the prediction of overdispersed, zero-inflated species abundance data. It illustrates predictive modeling procedure results without the general aim of assessing the performance of the methods on the MWN data set.

4.2. Types of Predictive Models

Better predictive models of biodiversity are essential for effective conservation and management of marine ecosystems facing growing anthropogenic pressures. Predictive modeling helps reveal patterns in biodiversity data, leading to an increase in studies focused on its applications in management contexts. This research investigates habitat data from three classification methods to build models predicting various uni- and multivariate fish biodiversity metrics. Traditional assessments often rely on simple species counts, but more complex uni- and multivariate metrics provide enhanced biodiversity insight, albeit with greater modeling challenges. By assessing a wider set of metrics, model

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

effectiveness can be officially evaluated. The hypotheses tested include: simpler univariate models will explain more deviance than complex multivariate ones; abiotic data will be more significant within each metric type; and observable thresholds for predictor variables will emerge, impacting data quality requirements in monitoring initiatives. Data from a marine monitoring program supplies habitat information, facilitating the examination of habitat–biodiversity relationships.

This includes biomass and abundance across six fish species groups that demonstrate various biodiversity aspects, such as total abundance, endemic richness, and community composition metrics that reflect species similarity at different resolutions. Three habitat data classification methods are analyzed: seafloor structure from high-resolution multibeam acoustic datasets, abiotic covariates from remote and direct observations, and biotic covariates derived from a new baited underwater video analysis approach. A comprehensive dataset with strong temporal designs and variable sampling effort supports this exploration, ultimately guiding the development of predictive habitat-biodiversity models. [20]

4.3. Model Validation and Calibration

Validation and calibration of IBIS enhance the robustness and reliability of outputs. Calibration optimizes control parameters to ensure model outputs align with known conditions within expected error margins. Benefits include improved model accuracy, adaptation to challenging conditions, and the use of constructed data for validation through test datasets. Validation utilizes data independent of the calibration process to assess the model against conditions not seen during calibration, giving confidence in outputs and understanding of their reliability.

However, validation can be lengthy, complex, and expensive. It often relies on subjective comparisons between independent data and model outputs, which may be manipulated to present a false sense of robustness. Despite these issues, validation is crucial in environmental modeling, especially when model outputs inform policy decisions. A recent poll indicated that over half of ecologists support validating model outputs before environmental decision-making and emphasizing uncertainty estimates. [21]

4.4. Applications in Biodiversity Assessment

An effective method is needed to assess the potential impacts of development projects on biodiversity. This proposed methodology involves an environmental impact assessment (EIA) and employs systematically compiled biotope maps along with data on species habitats. It includes 12 quality criteria and guidelines for quality evaluation. In Finland, obtaining a building permit requires an EIA program for projects with extensive environmental impacts.

The methodology is based on EIA guidelines and biodiversity data quality. A set of biotope maps and habitat descriptions supports this approach, utilizing satellite images to produce biotope maps in a GIS environment. Maps detail 16 habitat types and additional information on relevant protected habitats, excluding mires, water bodies, meadows, and consumption forests.

It is hypothesized that the planned actions cause minimal loss of biotopes, covering less than 1% of the total terrestrial area. European methodologies for assessing biodiversity impacts are analyzed, evaluating if they provide the necessary data. The methodology is critically reviewed, summarizing key evaluation findings regarding its design and applicability. Recommendations are made for improving the methodology and advancing its use. [3][22]

A transition tool, Figure 1, is employed to summarize the material that has been discussed and establish the integrated approaches.

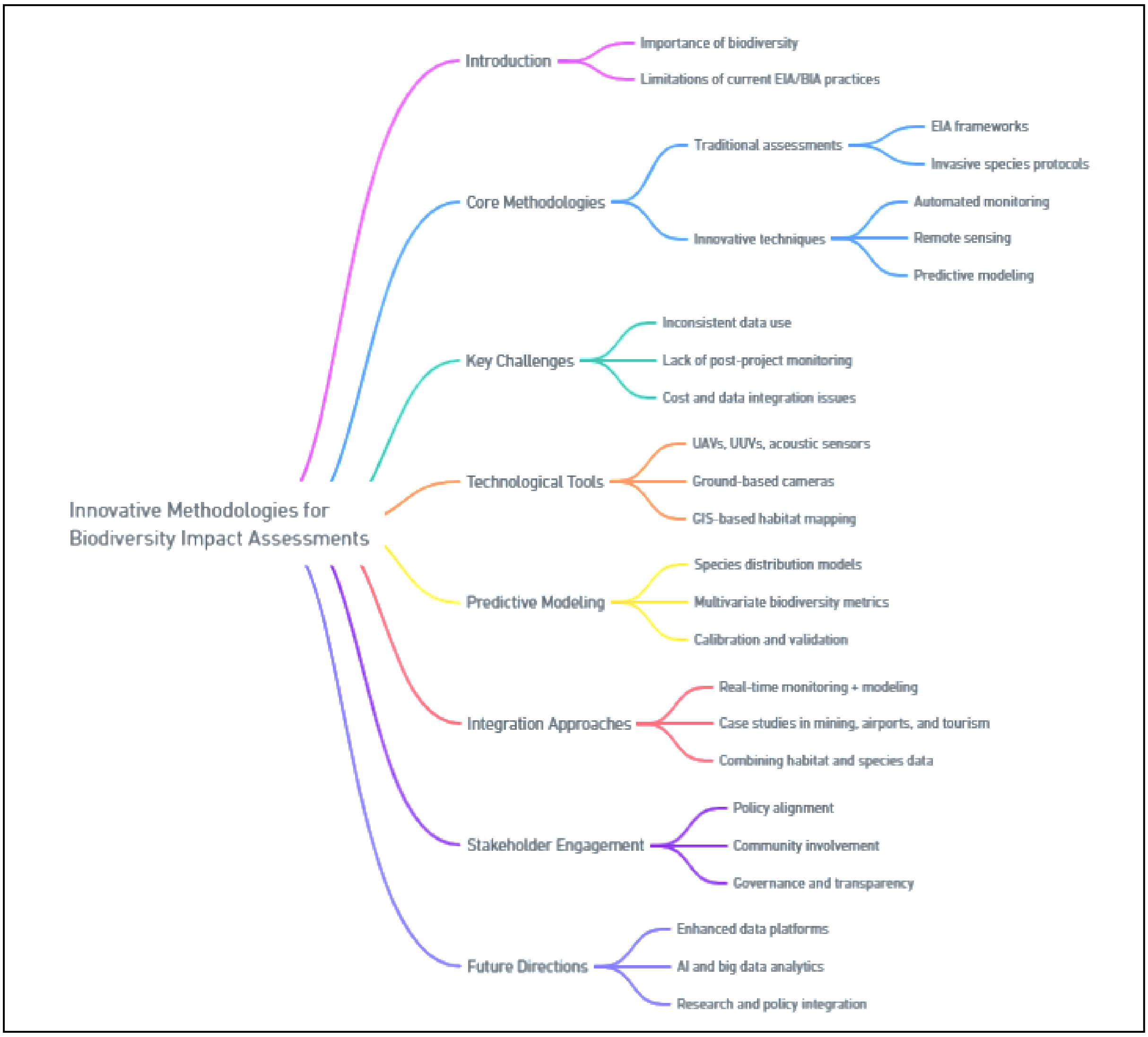

Figure 1: Innovative Methodologies for Biodiversity Impact Assessments

5. INTEGRATION OF TECHNOLOGIES

Public administrations in Europe assess the potential environmental impacts of plans and projects. Submitting entities must provide the competent authority with details on the study preparation techniques. This authority verifies these elements and offers feedback on their suitability. Environmental experts emphasize the need for an integrated view of Earth. General habitat mapping techniques have leveraged aerial photography, satellite imagery, field surveys, and land manager interviews. The advent of MultiSpectral Instruments Sentinel 2 satellite images could transform this field. A new GIS-based technique has been developed to evaluate potential biodiversity impacts from plans and projects using a habitat mapping approach.

Given the complexity of human activities, innovative methodologies for assessing biodiversity impacts are essential. In Europe, assessments must cover environmental features, particularly biodiversity and the ecosystems that support it; habitats and biotopes are crucial. Importantly, habitat and species preservation concerns should be addressed at a landscape or region-wide level, rather than just at a site-specific level. The Habitat Mapping Method has been effectively applied to assess potential impacts on biodiversity. [3] [23]

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

5.1. Combining Real-Time Monitoring and Predictive Modeling

To evaluate local ecosystem restoration approaches in predictive modeling, rapidly logged flora and fauna data, along with weather, soil, and microclimate indicators, are combined. This results from real-time monitoring that continuously assesses a spatial area through remote and close-up sensing. Major biodiversity assessment improvements arise from predictions involving wildlife or habitat keywords related to taxonomic classification and environmental coverage, including land, air, temperature, and soil. Gaussian space describes movement and disturbance forces associated with a species' exploration history. The model-free approach detects movements and disturbance events in habitat features or species activities like mating and foraging. Terrain characteristics, such as aspect and elevation, comprise an irregular species radial forces mix, recorded by previously uploaded species, with a taxa count. Occurrence is recorded if sightings happen in a cell. A simple latitude change of 4 to 5 degrees in the study area enhances result exploration accessibility but does not yield significant behavior changes. [24]

5.2. Case Studies of Integrated Approaches

The understanding of impacts on biodiversity and ecosystem services, and the development of procedures to mitigate these impacts, has been essential in conservation and environmental policy-making in Europe and globally for many years. Recognizing potential impacts on biodiversity from plans and projects began at least 30 years ago, with environmental impact assessments (EIA) mandated since the early 1970s. Assessing biodiversity in impact assessments requires various data, including land cover maps, habitat distribution, species distribution, location of protected areas, and data on pressures like pesticides, pollutants, road density, and buffer zones. General assessments can evaluate biodiversity's state and pressures using grid data. The project aimed to review methodologies for assessing impacts on biodiversity and ecosystem services, focusing on relevant sectors and best practices. Recommendations aimed to enhance effective methodologies in these areas. The overview of reviews highlighted that Member States promote alternative approaches centered on biodiversity and ecosystem services. Guidance documents illustrate expectations for impact assessments. Currently, Member States encourage some form of GIS analysis or mapping, showcasing GIS as a versatile and powerful technique for spatial data processing. [3] [25]

5.3. Benefits of Integration

Since the 1970s, there has been increased awareness of the environment's importance in decision-making, highlighting biodiversity's significance for life and human well-being. This section reviews methodologies that aim to support biodiversity, revealing challenges in accurately assessing its impact due to data quality and methodological issues. Notable gaps include inadequate monitoring methodologies for biodiversity assessment and unavailability of pre-development data for comparison. Additionally, current Environmental Impact Assessments (EIAs) focus mainly on construction effects, overlooking post-construction monitoring and often prioritizing wildlife-related biodiversity. The integration of biodiversity assessments in planning is rare due to: i) lack of policies mandating these assessments; ii) discrepancies in spatial/temporal scales; and iii) poor communication among developers, authorities, and conservationists about knowledge gaps. These issues undermine the credibility and effectiveness of impact assessment methodologies for biodiversity. [26][27]

Large infrastructure and industrial projects, linked to new roads and urbanization, significantly impact biodiversity. Monitoring biodiversity in these projects is now integral to the development process. Due to the unpredictability of many projects, particularly in developing nations, assessing impacts, planning mitigating interventions, and evaluating their success is crucial. A wide range of participants contribute data by developing customized biodiversity indicators, comparing ecosystems, species, and

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

genes, and providing qualitative habitat descriptions that support quantitative measures. These biological indicators are essential for industries to comply with increasing national and international regulations. In cases of significant biodiversity loss, Essential Habitat Loss Assessments are necessary. Projects like road construction, hydropower development, urban expansion, and mining often harm forest resources and the environment. While some impacts on forest cover are positive, project intensity can undermine its sustainability. Studies indicate that assessing the environmental, economic, and social impacts of such projects before implementation is vital. Since the 1980s, Environmental Impact Assessment (EIA) has been utilized to predict project effects, foster sustainable development, and safeguard the environment and public health. By the end of the 20th century, EIA became widely adopted, contributing to informed decision-making in international project funding. [28][29]

6.1. Types of Projects Affecting Biodiversity

Biodiversity is now recognized as essential for the planet's future development, but most assessment methodologies focus only on local biodiversity. Utilizing the pressure-state-impact-response (PSIR) framework, three methodologies are suggested to help create baseline data, assess impacts, and develop mitigation measures within environmental impact assessments (EIA). For instance, a case study on the Inner Mongolia hub airport project in China demonstrates how these methodologies aid in incorporating a comprehensive biodiversity perspective in EIA processes. As developing countries continue to alter natural land due to rapid economic growth, the significance of biodiversity concerns grows. However, quantitative methodologies for establishing mitigation measures to address negative impacts on biodiversity remain underdeveloped within EIA procedures. A proposed framework aims to quantify biodiversity impacts, enhancing the quality of mitigation measures in EIAs and addressing this longstanding issue. The framework's effectiveness is illustrated through a case study, showcasing optimal selections for mitigation measures. [29]

6.2. Assessment of Potential Impacts

Effective policy responses to invasive alien species (IAS) depend on assessing their impacts before empirical evidence is available. According to the biodiversity impact assessment framework, evaluating an organism's impact on native biodiversity requires comparative analysis. The proposals focus on understanding complexities and uncertainties within these comparisons, which need to be framed by analysts in strategic environmental assessments (SEA) or environmental impact assessments (EIA). A comparison must be made between conditions with the organism present or potentially present and those where it is absent. The organism could represent various project influences, including construction impacts and employment effects. Typical practices might overlook important implications, including indirect impacts. Additionally, pollutant dispersal modeling exemplifies a straightforward evidence-based approach to establishing a comparison distribution, despite potential complications. [22]

6.3. Mitigation Strategies

Assessment of measures for reducing negative impacts on biodiversity is crucial in this research. We evaluate the effectiveness and financial feasibility of the mitigation hierarchy, the standard for addressing developmental impacts on biodiversity, consisting of (1) avoidance, (2) minimization, (3) rectification, and (4) offset. Using the Kam Tin Comprehensive Development Area as a case study, the largest development zone in Hong Kong (over 3500 ha), we describe the effectiveness of these strategies. The avoidance strategy, which reduced the development area by 28.04%, diminished the predicted project impact from 7 species to 1 species. Additional evidence shows the impact on species was similar at 1.94 species when considering the avoided area. With biodiversity becoming a significant environmental issue, there is a pressing need for enhanced understanding of our direct and

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

indirect impacts. New legislation, changing consumer priorities, and increased media interest necessitate that environmental impact assessments (EIA) address ecological factors comprehensively. Innovative methodologies for biodiversity impact assessments are emerging from both academia and industry, ensuring projects remain environmentally sound. Concerns regarding the insufficient representation of sensitive ecosystems in current designations have been raised. A study introduced a method for broad-scale sensitivity mapping using specific criteria applied to standard data layers manageable via Geographic Information Systems (GIS). This method was utilized on Andros, Bahamas, to identify sensitive areas within draft tourist resort development proposals, leading to ecologically defensible planning while optimizing development potential. Such methodologies should be incorporated into EIA processes to protect the biodiversity of hosting territories. [30]

7.1. Identifying Sensitive Ecosystems

Environmental effects and their impacts on biodiversity are key priorities. Current impact assessment practices primarily rely on Environmental Impact Statements (EIS) to gauge the effects of proposed developments on air, land, water, and wildlife. Various land uses and resource developments impact the environment differently, affecting biodiversity uniquely. A review of present methodologies for assessing these potential impacts on biological resources is timely. This article examines current biodiversity impact assessment methodologies against the "five deadly sins" of impact assessment. Innovative approaches from other fields could enhance identification of sensitive ecosystems. Habitat is often used to gauge species biodiversity due to the lack of distribution data. However, focusing solely on habitat types overlooks habitat processes and overall diversity, indicating that expert judgment is irreplaceable. Therefore, new methodologies should complement existing expertise to enhance global and regional organizations' ability to assess environmental impacts quickly. Such methodologies may also benefit international agencies, national conservation bodies, and planning organizations. An "impact" is defined as any activity that affects change. [31]

7.2. Regulatory Frameworks and Policies

The 2020 pandemic disrupted business in environmental and social safeguarding, limiting ESIAs and ESMPs monitoring through conventional on-site visits or direct interaction. The rise of industrial activities poses significant threats to Earth’s ecosystems. Sustainable global development's effectiveness hinges on spatially decoupling industry from areas of high biological diversity. Actions must be initiated at all levels to protect ecosystem and species diversity. Local governments received information on the urgent need for proper drinking water use, single-use product disposal consequences, and community action opportunities.

7.3. Community Involvement and Stakeholder Engagement

Strengthening the role of science and technology in biodiversity conservation is crucial while considering human needs. The new regulation for managing forest and wildlife ecosystems reflects this principle. It aims to reconcile conservation and development by managing new forest areas not only for protection but also to provide benefits to local communities. This necessitates a special management category known as production forest with protection fountains, focusing on conserving biological diversity. The underlying assumption is that greater local benefits lead to more commitment to conservation. This approach, called community-based resource management or community forestry, includes community empowerment and resource utilization efforts. Since 2005, models of community forest enterprises have been established, with the Community Forest Enterprise (CFe) model involving 200 exclusive projects across various regions. The rationale for this initiative is that enhancing local benefits from forests improves their management, linking economic incentives directly to biodiversity conservation. Nevertheless, there’s an ongoing debate, with environmental organizations arguing that commercial forest utilization causes deforestation. These initiatives often provide funding for biodiversity projects or livelihood improvements, encouraging conservation through eco-tourism or non-timber products. However, compensation initiatives for landscape protection face criticism for not addressing community needs and national rights frameworks adequately. Innovative Trusts fund land purchases for protected areas from locals who agree to engage in conservation post-handover, shifting the perception of protected areas to model forestry management areas. Initial research into similar projects reveals unresolved challenges and significant shortcomings in funding, affecting poverty reduction and governance promotion, potentially undermining community interests. [32][33]

8. FUTURE DIRECTIONS IN BIODIVERSITY IMPACT ASSESSMENTS

Future Directions in Biodiversity Impact Assessments Government standards for managing ecological impacts of development projects include conducting one of eight impact assessments prior to approval, adhering to principles, producing alternative feasible project statements, and developing environmental management plans. Several innovative methodologies for ecosystem impact assessments are currently available, including biodiversity assessments, connectivity analysis, indicator species, and ecological level analyses. Utilizing these methodologies offers several potential benefits separately and collectively. Eight key benefits of improved methods for assessing ecological impacts and proposed strategies for achieving these improvements are examined with a focus on biodiversity. A case study on recently developed restrictions on vegetation clearing in Queensland illustrates these methods. Biodiversity impact assessment methods that consider spatial attributes have been developed at various scales, leading to outcomes that accurately reflect potential adverse impacts on biodiversity. Innovations in detecting biodiversity thresholds, representation requirements, and advancements in bioclimatic modeling enhance current methodologies. The development and application of these innovative methodologies aim to improve the accuracy of biodiversity evaluations within impact assessments. Understanding the likely consequences of various projects or processes on biodiversity aids in effective management. Facilitating assessments of broadscale changes in connectivity is also essential. [3]

8.1. Emerging Technologies

This special issue of Environmental Impact Assessment Review features papers from a workshop on biodiversity impact assessments held at the United Nations Biodiversity Conference in Nagoya, Japan, in November 2016. It showcases a variety of innovative methodologies for assessing biodiversity impacts, covering areas like data gathering and processing technologies, linking data across scales, and participatory approaches. The discussion emphasizes trends in science relevant to biodiversity assessments and includes case studies highlighting systems for evaluating impacts on biodiversity. These methodologies and technological advances directly support the implementation of the Strategic Plan for Biodiversity (2011–2020) and the Aichi Targets. Individual papers are introduced, and their contributions along with the requirements for the final Aichi targets on assessment science are examined. [34][35]

8.2. Policy Recommendations

The development and uptake of effective policies and management plans rely on impact assessments that evaluate environmental, health, and social impacts of proposed interventions. These assessments provide decision-makers with evidence about potential benefits and drawbacks, guiding informed choices and highlighting necessary mitigation measures. They also foster transparency and dialogue with stakeholders and the public. Recently, impact assessments have gained attention within European Union policies, being required for over 80 policy instruments to evaluate various thematic areas. Concerns exist that vested interests may influence these assessments, shaping evidence based

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

on those supplying information. The European Commission and the European Parliament have sought to enhance transparency and accountability in the process, implementing measures in 2010 to strengthen governance through public consultation and conflict of interest alleviation. Biodiversity, which encompasses the variability among living organisms across ecosystems, is now a key focus in environmental assessments and spatial planning globally. Legal frameworks for biodiversity conservation have been established, but protection extends beyond designated protected areas. Spatial planning and environmental assessments present opportunities for enhanced biodiversity protection. Addressing biodiversity objectives in development and planning requires an understanding of the impacts on biodiversity. Factors such as changes in land use influence biodiversity by altering nutrient availability and hydrological conditions. Generally, the use of biodiversity data can be broken down into five steps: (i) defining the affected area, (ii) characterizing baseline biodiversity status, (iii) identifying potential project effects, (iv) designing appropriate mitigation measures, and (v) identifying compensatory actions where feasible. [22][3]

8.3. Research Gaps and Opportunities

The consideration of biodiversity in impact assessments and spatial planning requires detailed biodiversity data in various formats and scales, from genes to ecosystem services. Over the past 25 years, efforts across Europe have aimed to enhance methodologies for utilizing biodiversity data in spatial planning and assessments through guidance documents, regulatory changes, and collaboration among experts. Research gaps persist, such as developing licensing for improved data access via intermediary platforms, establishing data quality governance, and increasing spatially explicit biodiversity data for integration with existing platforms, especially concerning marine and freshwater ecosystems. This effort reviews current methods and platforms to aid public authorities and optimize future initiatives. Key obstacles include data standardization, quality governance, licensing for data providers, and identifying funding targets to fill coverage gaps in biodiversity aspects. Additional actions are recommended to enhance the quantity, quality, and accessibility of biodiversity data, catering to the specific needs of various decision-making levels and institutions. [3][36]

9. CONCLUSION

Legislation globally mandates the assessment of biological diversity impacts stemming from legislative and development plans, typically achieved through standard spatial assessments based on environmental and biological variables compared to a computer-generated baseline. However, such assessments often overlook the intricate consequences on biological diversity, like how habitats that filter dispersing propagules can influence distant areas. Additionally, wildlife nurseries might not be proximate to disturbances, complicating impact characterization. While there are advanced methodologies involving extensive field data sampling of biodiversity, their high costs limit usage, necessitating more accessible evaluation methods with solid statistical backing. This methodology assesses developmental impacts on biological values extending well beyond euclidian constraints. To prioritize affected biodiversity over development decisions, it is crucial to utilize ecologically sound methodologies. A species-specific approach aligns with legislative priorities due to the direct nature of species-specific impacts. Random surveys of plant and animal life were conducted at both the development site and a baseline location. Two case studies highlight common impacts from development: colonization by scrubland birds in cleared areas, and the reduction of native plant and invertebrate populations due to altered wetland hydroperiods. These studies utilize a ‘species’ methodology and underscore the necessity of viewing expected and actual species responses as distinct when assessing biodiversity impacts of a development. The assessment considered permits and favorable habitat areas in a hierarchical structure, creating a dose-response template for potential effects. Modelling of a cleared scenario against a control baseline involved two main steps: first,

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

modelling the expected effects of clearing within the study boundary to adjust for impacts on biological values; secondly, comparing modeled and observed effects against expected models for more accurate predictions.

References

1) K. Bruce, R. C. Blackman, S. J. Bourlat, and M. Hellström, "A practical guide to DNA-based methods for biodiversity assessment," 2021. DOI: 10.3897/ab.e68634
2) S. Hoffmann, "Challenges and opportunities of area-based conservation in reaching biodiversity and sustainability goals," Biodiversity and Conservation, 2022. https://doi.org/10.1007/s10531-021-02340-2
3) E. Underwood, K. Taylor, and G. Tucker, "The use of biodiversity data in spatial planning and impact assessment in Europe," 2018. doi: 10.3897/rio.4.e28045
4) M. Eliantonio and T. Ivanchykava, "Transnationality in the eia and sea Directives and the Blind Spots of Judicial Control," European Environmental & Planning Law, 2025. https://doi.org/10.1163/18760104-22010202
5) D. Bose, R. Bhattacharya, T. Kaur, R. Pandya, "Innovative approaches for carbon capture and storage as crucial measures for emission reduction within industrial sectors," Carbon Capture Science, vol. 2024, Elsevier. https://doi.org/10.1016/j.ccst.2024.100238
6) A. L. Caro-Gonzalez, A. Nita, J. Toro, "From procedural to transformative: a review of the evolution of effectiveness in EIA," Environmental Impact Assessment, vol. 2023, Elsevier, 2023. https://doi.org/10.1016/j.eiar.2023.107256
7) A. Nita, S. Fineran, and L. Rozylowicz, "Researchers' perspective on the main strengths and weaknesses of Environmental Impact Assessment (EIA) procedures," Environmental Impact Assessment, vol. 2022, Elsevier. https://doi.org/10.1016/j.eiar.2021.106690
8) Á Enríquez-de-Salamanca, "Project justification and EIA: Anything goes?," Environmental Impact Assessment Review, 2021. https://doi.org/10.1016/j.eiar.2020.106540
9) S. Sethi, R. Ewers, N. Jones, D. Orme et al., "Robust, real-time and autonomous monitoring of ecosystems with an open, low-cost, networked device," 2018. DOI: 10.1111/2041-210X.13089
10) K. Sherman, C. Dahlgren, C. Dunn, D. Claridge et al., "Implementation of Access and Benefit Sharing in The Bahamas: A Precautionary Tale," Conservation, 2025. https://doi.org/10.3390/conservation5010003
11) A. P. Christie, H. Downey, W. F. Frick, et al., "A practical conservation tool to combine diverse types of evidence for transparent evidence-based decision-making," *Conservation Science and Practice*, vol. 2022, Wiley Online Library. DOI: 10.1111/csp2.579
12) J. Wiens, R. Sutter, M. Anderson, J. Blanchard et al., "Selecting and conserving lands for biodiversity: The role of remote sensing," 2009. Doi: 10.1016/j.rse.2008.06.020
13) S. Kumari, S. Agarwal, N. K. Agrawal, A. Agarwal, "A Comprehensive Review of Remote Sensing Technologies for Improved Geological Disaster Management," Geological…, vol. 2025, Wiley Online Library. https://doi.org/10.1002/gj.5072

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

14) L. K. Torres Gil, D. Valdelamar Martínez, and M. Saba, "The widespread use of remote sensing in asbestos, vegetation, oil and gas, and geology applications," Atmosphere, 2023. https://doi.org/10.3390/atmos14010172

15) T. Edward Martin, J. Nightingale, J. Baddams, J. Monkhouse et al., "Variability in the Effectiveness of Two Ornithological Survey Methods between Tropical Forest Ecosystems," 2017. doi: 10.1371/journal.pone.0169786

16) M. R. Blake, M. A. Fylling, D. S. Leick, "Evaluating two avian monitoring tools for detecting relative abundance of species during autumn migration," Journal of Field Biology, 2023. https://doi.org/10.5751/JFO-00318-940304

17) D. Triebel, W. Reichert, S. Bosert, M. Feulner et al., "A generic workflow for effective sampling of environmental vouchers with UUID assignment and image processing," 2018. doi: 10.1093/database/bax096

18) K. L. Yates, C. Mellin, M. Julian Caley, B. T. Radford et al., "Models of Marine Fish Biodiversity: Assessing Predictors from Three Habitat Classification Schemes," 2016. doi: 10.1371/journal.pone.0155634

19) G. Robin and C. Le Hasif, "Technical report: Impact of evaluation metrics and sampling on the comparison of machine learning methods for biodiversity indicators prediction," 2021. Link: 2108.07480

20) K. N. Shivaprakash, N. Swami, S. Mysorekar, R. Arora, "Potential for artificial intelligence (AI) and machine learning (ML) applications in biodiversity conservation, managing forests, and related services in India," Sustainability, vol. 2022. https://doi.org/10.3390/su14127154

21) M. B. Araújo, R. P. Anderson, A. Márcia Barbosa, C. M. Beale et al., "Standards for distribution models in biodiversity assessments," 2019.doi 10.1126/sciadv.aat4858

22) A. Turbe, D. Strubbe, E. Mori, M. Carrete et al., "Assessing the assessments: evaluation of four impact assessment protocols for invasive alien species," 2017. DOI: 10.1111/ddi.12528

23) H. Guo, D. Liang, Z. Sun, F. Chen, X. Wang, J. Li, and L. Zhu, "Measuring and evaluating SDG indicators with Big Earth Data," Science Bulletin, vol. 67, no. 12, pp. 1234-1246, 2022. https://doi.org/10.1016/j.scib.2022.07.015

24) D. Nemitz, "An assessment of sampling detectability for global biodiversity monitoring: results from sampling GRIDs in different climatic regions," 2008.
https://core.ac.uk/download/150155203.pdf

25) M. J. Mashala, T. Dube, B. T. Mudereri, K. K. Ayisi, "A systematic review on advancements in remote sensing for assessing and monitoring land use and land cover changes impacts on surface water resources," Remote Sensing, 2023. https://doi.org/10.3390/rs15163926

26) S. R Weiskopf, B. J E Myers, M. Isabel Arce-Plata, J. L Blanchard et al., "A Conceptual Framework to Integrate Biodiversity, Ecosystem Function, and Ecosystem Service Models," 2022. doi: 10.1093/biosci/biac074

27) J. Baert Wiener and D. Lima Ribeiro, "Impact Assessment: Diffusion and Integration," 2015. 163084721.pdf

28) A. Degife, "Towards Mainstreaming Environmental Impact Assessment into Housing Development Projects in Ethiopia: The Case of Koye-Feche Condominium Housing Development Project, Addis Ababa," 2018. CER-Vol.10 No.1 2018.pdf

DOI: 10.5281/zenodo.15377911
Vol: 62 | Issue: 05 | 2025

29) E. Sub Kim, D. Kun Lee, and J. Choi, "Evaluating the effectiveness of mitigation measures in environmental impact assessments: A comprehensive review of development projects in Korea," 2024. doi: 10.1016/j.heliyon.2024.e31647

30) K. M. Wood, "A Multi-Criteria Evaluation Model for Rapid Assessment and GIS Mapping of Ecological Values for Informed Land Use in Small-Island Developing States," 2017. Citable link http://nrs.harvard.edu/urn-3:HUL.InstRepos:33797334

31) R. Puig-Gironès and J. Real, "A comprehensive but practical methodology for selecting biological indicators for long-term monitoring," 2022. doi: 10.1371/journal.pone.0265246

32) J. Dyer, L. C. Stringer, A. J. Dougill, J. Leventon et al., "Assessing participatory practices in community-based natural resource management: experiences in community engagement from southern Africa," 2014. https://doi.org/10.1016/j.jenvman.2013.11.057

33) B. Wachi, "Assessing the scope of effectiveness of stakeholder engagement in the development and implementation of the Environmental Management Plan for the Berg Water Project in the Western Cape Province, South Africa," 2016. http://hdl.handle.net/11427/22721

34) A. Bush, R. Sollmann, A. Wilting, K. Bohmann et al., "Connecting Earth observation to high-throughput biodiversity data," 2017. https://doi.org/10.1038/s41559-017-0176

35) J. J Lahoz-Monfort and M. J L Magrath, "A Comprehensive Overview of Technologies for Species and Habitat Monitoring and Conservation," 2021. doi: 10.1093/biosci/biab073

36) L. Tydecks, J. M. Jeschke, M. Wolf, G. Singer et al., "Spatial and topical imbalances in biodiversity research," 2018. https://doi.org/10.1371/journal.pone.0199327